In Vivo Metabolism of Apolipoprotein A-I in a Patient With Homozygous Familial Hypercholesterolemia


Familial hypercholesterolemia (FH), caused by a defect in the low density lipoprotein (LDL) receptor, results in high plasma concentrations of LDL cholesterol due to both overproduction and delayed catabolism of LDL. FH is also associated with significantly lower levels of plasma high density lipoprotein cholesterol and apolipoprotein (apo) A-I in both heterozygous and homozygous patients. However, the metabolic basis of the hypoalphalipoproteinemia in FH has not been elucidated. We investigated the kinetics of apo A-I in a homozygous FH patient and two normal control subjects by using endogenous labeling with a stable isotopically labeled amino acid. Study subjects were administered a primed constant infusion of \(^{13}\)C-phenylalanine for 12 hours. Apolipoproteins were isolated from plasma drawn at selected time points and analyzed for their isotopic enrichment by gas chromatography-mass spectrometry. The fractional catabolic rate of apo A-I in the FH subject was found to be substantially increased (0.38 day\(^{-1}\)) compared with that of the normal subjects (mean, 0.26 day\(^{-1}\)). In addition, the apo A-I production rate was decreased in the FH subject (6.5 mg/kg • day\(^{-1}\)) compared with the normal subjects (mean, 11.1 mg/kg • day\(^{-1}\)). In conclusion, the low levels of high density lipoprotein cholesterol and apo A-I in this homozygous FH patient are due to the combined metabolic defects of increased apo A-I catabolism and decreased apo A-I production. (Arteriosclerosis and Thrombosis 1992;12:843–848)

KEY WORDS • familial hypercholesterolemia • fractional catabolic rate • apolipoprotein A-I • low density lipoproteins

Familial hypercholesterolemia (FH) is caused by a variety of genetic defects in the gene for the low density lipoprotein (LDL) receptor. Heterozygotes for FH have approximately twofold elevations in plasma LDL cholesterol concentrations, whereas FH homozygotes have LDL cholesterol levels elevated as much as sixfold. Plasma apolipoprotein B-100 (apo B-100), apo E, and lipoprotein(a) (Lp[a]) concentrations are also significantly elevated in FH. Conversely, plasma high density lipoprotein (HDL) cholesterol and apo A-I levels are significantly decreased in both homozygous and heterozygous FH.

The in vivo metabolism of apo B–containing lipoproteins has been extensively studied in FH, establishing that there is overproduction as well as delayed catabolism of apo B–containing lipoproteins in this disease.

Apo E catabolism is also delayed in FH, presumably because of decreased LDL receptor–mediated catabolism. We have demonstrated that the fractional catabolic rate (FCR) of Lp(a) in homozygous FH is decreased as well.

In contrast, there has been no investigation of the metabolic basis of the low plasma HDL cholesterol and apo A-I levels in FH. In this article we report the results of a kinetic study of apo A-I in a patient with homozygous FH that used endogenous labeling with a primed constant infusion of a stable isotopically labeled amino acid.

Methods

Study Subjects

Studies were performed in a homozygous FH patient and two normal control subjects. The FH subject is a 26-year-old man who is homozygous for a class 1 defect in the LDL receptor, with no detectable receptors on the cell surfaces as determined by functional and immunologic studies. The medical history of this patient includes a myocardial infarction (7 years of age), ileal bypass surgery (9 years of age), and bilateral carotid endarterectomies (25 years of age). The patient usually undergoes biweekly LDL apheresis, which was stopped 5 weeks before this study to achieve lipoprotein steady-state conditions. Total cholesterol, LDL cholesterol, apo B, and apo E levels in the FH subject were elevated, whereas HDL cholesterol and apo A-I levels were...
reduced. The apo E phenotype of the FH subject was apo E-3/3. The two control subjects, who were 22- and 25-year-old men, had normal plasma lipid and lipoprotein levels. Their apo E phenotypes were apo E-3/4 and apo E-3/3, respectively. Clinical characteristics and laboratory values of the study subjects are summarized in Table 1.

The study protocol was approved by the Internal Review Board of the National Heart, Lung, and Blood Institute, and informed consent was given by each of the participants.

Preparation of Stable Isotopically Labeled Amino Acid

The stable isotopically labeled amino acid used in this study was a custom-synthesized 13C6-labeled l-phenylalanine, with the six labeled carbons positioned in the aromatic ring (Cambridge Isotope Laboratories, Woburn, Mass.). Multiple labeling of the amino acid was selected because the additional mass shifts the labeled amino acid peak well out of the range of the peak due to the natural abundance of heavy isotopes on mass spectrometric analysis. The use of 13C6-labeled phenylalanine therefore significantly increases the accuracy of the mass spectrometric detection of the tracer because the background level is virtually zero. Phenylalanine was chosen as the tracer amino acid in part because it undergoes irreversible conversion to tyrosine by the hepatic intracellular enzyme phenylalanine hydroxylase,18 resulting in the generation of sixfold-labeled tyrosine in plasma. A plasma steady state of labeled tyrosine thus reflects a steady state within the physiological salt solution, sterile filtered, and tested for pyrogenicity and sterility before the study.

Study Protocol

Three days before the start of the study, subjects were placed on a controlled isovolumetric diet containing 37% fat, 47% carbohydrate, and 16% protein, 200 mg cholester-ol/1,000 kcal, and a polyunsaturated to saturated fat ratio of approximately 0.3. After a 12-hour fast, the 13C6-phenylalanine was administered as a priming bolus of 550 μg/kg immediately followed by a constant infusion of 12 μg·kg⁻¹·min⁻¹ over a period of 12 hours. Meals were provided in small equal portions every 2 hours during the infusion. Blood samples were drawn before the priming bolus, 10 minutes after the bolus, and then at selected times during the infusion. Blood was drawn into tubes containing EDTA at a final concentration of 0.1% (wt/vol). Plasma was separated by low-speed centrifugation for 30 minutes at 4°C. Sodium azide and aproatin were added to the plasma at a final concentration of 0.05% (wt/vol) and 200 kIU/ml, respectively.

Isolation of Free Plasma Amino Acids

Free plasma amino acids were isolated from 0.5 ml plasma by cation-exchange column chromatography as previously described.19 Briefly, 1 ml 30% acetic acid was added to 0.5 ml plasma and applied to prefilled PolyPrep columns (Bio-Rad, Richmond, Calif.). The columns were washed with 8 ml distilled water and eluted with 5 ml 4N NH₄OH directly into 5-ml reaction vials (Pierce, Rockford, Ill.).

Isolation and Preparation of Apolipoproteins

Lipoprotein density subfractions were isolated by sequential ultracentrifugation20 of 5 ml plasma collected at selected time points. Very low density lipoproteins (VLDLs; d<1.006 g/ml) and HDL (d=1.063-1.21 g/ml) were used for isolation of apolipoproteins. Apo B-100 was isolated from delipidated VLDL by preparative discontinuous gradient sodium dodecyl sulfate-polycrylamide gel electrophoresis (SDS-PAGE) (5%/15% acrylamide) using a modification of a previously published method.21 Approximately 0.5 mg VLDL protein was delipidated using chloroform/methanol (2:1, vol/vol) and solubilized in 2% SDS containing 0.1 M tris(hydroxymethyl)aminomethane HCl (pH 6.8) and 1% (vol/vol) diethiothreitol. The samples were heated at 100°C for 10 minutes and applied to a 3-mm-thick vertical slab gel (12x14 cm). After electrophoresis the gels were stained with Coomasie Blue R-250 (Bio-Rad) and destained in a solution of 5% (vol/vol) methanol and 7.5% (vol/vol) acetic acid. Apo A-I was isolated from HDL by preparative isoelectric focusing.22 After dialysis, lyophilization, and delipidation of HDL as described above, approximately 1 mg HDL protein was solubilized in buffer containing 8.6 M urea and 1% (vol/vol) dithiothreitol. Isolelectric focusing was carried out in a 3-mm-thick vertical slab gel using 7.5% acrylamide, 8 M urea, and 2% (vol/vol) Pharmalyte, pH 4–6.5 (Pharmacia, Piscataway, N.J.). Gels were electrofocused at 250 V for 20 hours at 4°C with 0.02 M NaOH and 0.01 M H₂PO₄ as the upper and lower buffers, respectively. After electrophoresis the gels were stained with Coomasie Blue G-250 (Bio-Rad). Stained apolipoprotein bands were cut from the gels, and the gel slices were dried in a 90°C oven and then hydrolyzed in 6N HCl (Pierce) for 24 hours at 110°C under nitrogen vacuum. After removal of HCl by speed-vac lyophilization the samples were dissolved in 50% (vol/vol) acetic acid and applied to cation-exchange columns as described above. Amino acids were recovered by elution with 4N NH₄OH into reaction vials.
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FIGURE 1. Line plots of isotopic enrichment values for plasma free phenylalanine in two control subjects (panels A and B) and the familial hypercholesterolemia subject (panel C).

Gas Chromatographic-Mass Spectrometric Analysis

Recovered amino acids were derivatized to the N-heptafluorobutyrl isobutyl esters as previously described. 20 Briefly, 500 μl isobutylic HCl (Alltech Associates, Inc., Deerfield, Ill.) was added to the samples, and vials were heated for 1 hour at 110°C, cooled to room temperature, and lyophilized. The residue was dissolved in 200 μl high-performance liquid chromatography-grade ethyl acetate and further treated with 150 μl heptafluorobutyric acid (Alltech Associates Inc.) at 150°C for 10 minutes to complete the derivatization. After cooling to room temperature and lyophilizing to dryness, the derivatized product was dissolved in 100 μl ethyl acetate and stored at -20°C until gas chromatographic-mass spectrometric (GC/MS) analysis.

Samples were analyzed on a Finnigan MAT 4500 GC/MS (Finnigan, San Jose, Calif.) in the chemical ionization mode with isobutane as the reagent gas. The selected positively charged ions of 418 m/z for phenylalanine, 424 m/z for 13C6-phenylalanine, 630 m/z for tyrosine, and 636 m/z for 13C6-tyrosine were monitored. At least three measurements were made of each apolipoprotein at each time point. In addition, a blank gel slice comparable in size to the protein gel slices was analyzed as a control. The amount of unlabeled phenylalanine in the blank gel slices was always less than 3% of the total phenylalanine in the study samples. The isotopic enrichment of the sample was determined as the fraction of labeled to total (labeled plus unlabeled) phenylalanine.

Analytical Methods

Apo A-I and apo B were quantified by enzyme-linked immunosorbent assay as previously described. 24-25 Apo E was quantified by radioimmunoassay. 26 Plasma cholesterol and triglycerides were quantified by using an enzymatic assay (Wako Pure Chemical Industries, Ltd., Houston, Tex.). HDL cholesterol was determined in plasma after dextran sulfate precipitation. 27 Determination of the fractional synthetic rate (FSR) of apo A-I was performed as recently reported. 28-31 The isotopic enrichment of VLDL apo B-100 at plateau was used as an estimate of the precursor pool enrichment for apo A-I synthesis. The isotopic enrichment of apo A-I was divided by the precursor enrichment to obtain a "corrected isotopic enrichment." A "best-fit" line was fit to the data by using linear regression analysis. The apo A-I FSR was determined as the slope of the apo A-I corrected isotopic enrichment curve. At steady state, the FSR equals the FCR. The apo A-I production rate (PR) was determined by the formula

PR = [FSR x apo A-I concentration x plasma volume] / body weight

Plasma volume was assumed to be 4% of body weight.

Results

A plasma steady state of free 13C6-phenylalanine was achieved within 30 minutes in all three study subjects (Figure 1). The mean isotopic enrichment of 13C6-phenylalanine at steady state was 5.6±0.7% in the FH subject, 5.7±0.4% in control subject 1, and 4.9±0.3% in control subject 2. A steady state of endogenously de-
TABLE 2. Kinetic Parameters of Apo A-I Metabolism

<table>
<thead>
<tr>
<th>Subject</th>
<th>FSR (day$^{-1}$)</th>
<th>Apo A-I (mg/dl)</th>
<th>PR (mg/kg·day$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FH subject</td>
<td>0.376</td>
<td>44</td>
<td>6.2</td>
</tr>
<tr>
<td>Control 1</td>
<td>0.230</td>
<td>109</td>
<td>9.7</td>
</tr>
<tr>
<td>Control 2</td>
<td>0.286</td>
<td>111</td>
<td>10.7</td>
</tr>
</tbody>
</table>

Apo, apolipoprotein; FSR, fractional synthetic rate; PR, production rate; FH, familial hypercholesterolemia.
may exist a feedback system involving the LDL receptor that regulates the hepatic expression of both apo A-I and apo B. It is well established that FH fibroblasts have markedly impaired ability to normally regulate the 3-hydroxy-3-methylglutaryl coenzyme A reductase gene \( \text{HMG-CoA} \); FH hepatocytes also have abnormal intracellular cholesterol homeostasis that may affect the production of apo A-I and apo B.

In conclusion, we have established that low levels of HDL cholesterol and apo A-I in a homozygous FH subject are due to a combined metabolic defect of increased apo A-I catabolism and decreased apo A-I production compared with control subjects studied under identical conditions. These results provide new insights into the regulation of apo A-I metabolism in FH.

Acknowledgments

We wish to thank Yoshiko Doherty for excellent technical assistance, George Grimes and the Pharmaceutical Development Service for preparation of the phenylalanine, the nursing staff of the 8 East ward of the NIH Clinical Center, Patti Riggs for dietary support, Joanie Gault for the preparation of the manuscript, and the study subjects for participating in this study.

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doi: 10.1161/01.ATV.12.7.843

Arteriosclerosis, Thrombosis, and Vascular Biology is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 1079-5642. Online ISSN: 1524-4636

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